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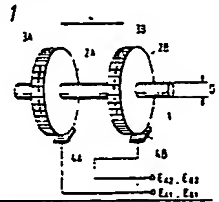
(54) Torque detecting apparatus.

(57) A torque detecting apparatus comprises a first magnetic angular sensor (3A, 4A) outputting a sine-wave output (E_{A1}) and a cosine-wave output (E_{B1}) corresponding to positions of rotation of a rotary drum (2A) being fitted a rotating drive shaft (1). A second magnetic angular sensor (3B, 4B) outputs a sine-wave output (E_{A2}) and a cosine-wave output (E_{B2}) corresponding to positions of rotation of another rotary drum (2B) being fitted on the rotating drive shaft (1). In case of the respective other output of the sine-wave output or the cosine-wave output of the first or the second magnetic angular sensor is varied while one output of the sine-wave output or the cosine-wave output in the first or the second magnetic angular sensor is not varied, the one output cosine-wave output or the sine-wave output of the first or the second magnetic angular sensor is determined to be faulty and an abnormality signal is delivered by a judging means.

FIG. 1



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TORQUE DETECTING APPARATUS

Background of the Invention:

The present invention relates to a torque detecting apparatus in which a fault of the torque detecting apparatus is detected, and more particularly to a torque detecting apparatus in which a relative shift of positions being caused by the torsion of a shaft is detected, or to a torque controlling apparatus for an electric driven power steering construction in a driving force assisting apparatus whose main component comprises a torque detecting apparatus, or the like.

Conventional torque detecting apparatuses are so constructed that the outputs are obtained from each of the magnetic sensors respectively corresponding to the angles of rotation of the rotary drums fitted to the opposite ends of the rotating drive shaft and the phase difference signals from these magnetic sensors are executed to determine a torque by an executing circuit, as shown in Japanese Patent Laid-Open No. 239031/1987 for example.

In the prior art stated above, no consideration is given about a method of detecting a torque when the rotating drive shaft stops, and further no consideration is given at all to the fault of the magnetic sensors itself such as wire break-down and short circuit and others such as break-down and short circuit in wiring, which produces a problem that the fault cannot be detected.

Summary of the Invention:

An object of the present invention is to provide a torque detecting apparatus wherein a fault of a position detecting means itself such as a magnetic angular sensor can be detected easily.

Another object of the present invention is to provide a torque detecting apparatus wherein a fault of an electric wiring of a position detecting means such as a magnetic angular sensor can be detected easily.

A further object of the present invention is to provide a torque detecting apparatus wherein an abnormality signal of a position detecting means such as a magnetic angular sensor can be sent to a system so as to protect the torque detecting apparatus.

A further object of the present invention is to provide a torque detecting apparatus wherein an abnormality signal of a position detecting means such as a magnetic angular sensor can be sent to a system such as an electric driven power steering assist construction so as to protect the system.

A further object of the present invention is to provide a torque detecting apparatus wherein an abnormality signal of a position detecting means such as a magnetic angular sensor can be sent to a system such as an electric driven power steering assist construction so as to prevent an unexpected or undesirable operation of the system.

In accordance with the present invention, a torque detecting apparatus comprises a first rotary body being fitted on a drive side on a rotating drive shaft, a second rotary body being fitted on a load side on said rotating drive shaft, a first position detecting means being disposed oppositely and facing the first rotary body, a second position detecting means being disposed oppositely and facing the second rotary body, the first position detecting means generates a first output and a second output corresponding to positions of rotation of the first rotary body, the second position detecting means generates a third output and a fourth output corresponding to positions of rotation of the second rotary body, and a torque executing means for executing a first angle from the first output of the first rotary body and the second output of the first rotary body and for executing a second angle from the third output of the second rotary body and the fourth output of the second rotary body and further for executing a torque from a phase difference between the first angle and the second angle.

The torque detecting apparatus comprises further a judging and outputting means for judging a fault and for outputting an abnormality signal, when one output of the first output and the second output in the first rotary body is determined to be the faulty and the abnormality signal is delivered, in case of the other output of the first output and the second output in the first rotary body is varied while the one output of the first output and the second output in the first rotary body is not varied.

The torque detecting apparatus comprises further a judging and outputting means for judging a fault and for outputting an abnormality signal, when one output of the third output and the fourth output in the second rotary body is determined to be the faulty and the abnormality signal is delivered, in case of the other output of the third output and the fourth output in the second rotary body is varied while the one output of the third output and the fourth output in the second rotary body is not varied.

The torque detecting apparatus is constituted by the first position detecting means and the second position detecting means disposed oppositely to the first rotary body and the second rotary body fixed respectively on the drive side and the load side on the rotative drive shaft, respectively, and a plurality of signals are outputted from the first position detecting means and the second position detecting means.

Since these output signals are varied in accordance with the rotation of the first rotary body and the second rotary body, the positions of rotation of the two rotary bodies can be known from the amplitude of these output signals. Since the rotational positions of the two rotary bodies are known in this way, a difference between these positions, i.e. an angular difference, turns to be an angle of a torsion, and thus a torque can be detected therefrom.

Now, when a plurality of output signals of each rotary body are checked up and it is found that only one output signal is not varied while others are varied, the one output signal can be determined to be faulty. A fault can be detected quickly, in this way, by checking up the plurality of output signals obtained from the first and the second rotary bodies.

According to the present invention, any fault of a torque detecting apparatus can be detected easily. Therefore, since any abnormality and fault in the torque detecting apparatus can be detected, an unexpected or an undesirable operation of the torque detecting apparatus is prevented, thus high safety in the torque detecting apparatus can be secured.

Further, any fault in a torque controlling apparatus for an electric power assist construction is detected easily when an assist torque means such an electric motor is cut off from a rotating drive shaft. Therefore, an unexpected or an undesirable operation of the torque controlling apparatus is prevented, thus high safety in the torque controlling apparatus can be secured.

Brief Description of the Drawings:

Fig. 1 is a schematic structural view of one embodiment of a torque detecting apparatus according to the present invention;

Fig. 2 is a detailed view of a rotary drum and a magnetic angular sensor constituting a torque detecting apparatus;

Fig. 3A is a developed view of a magnetic substance of a rotary drum;

Fig. 3B is a plan view of a magnetic angular sensor in relation to a magnetic substance of a rotary drum;

Fig. 4 is an illustration of magnetic poles recorded on a magnetic substance of a rotary drum and of outputs of the torque sensor;

Fig. 5 is a connection diagram of a three-terminal contact of magnetro-resistance effect elements;

Fig. 6A is a diagram of output waveforms obtained from a middle point of a three-terminal contact;

Fig. 6B is a diagram of output waveforms obtained from a middle point of a three-terminal contact;

Fig. 7A is diagrams for a method of detecting a load torque on the basis of the same output waveforms obtained from a magnetic angular sensor;

Fig. 7B is diagrams for a method of detecting a load torque on the basis of the same output waveforms obtained form a magnetic angular sensor;

Fig. 8A is diagrams of one embodiment of a magnetic angular sensor of the present invention for obtaining sine-wave outputs;

Fig. 8B is a connection diagram of magnetro-resistance effect elements;

Fig. 9 is a developed view of a rotary drum and a magnetic angular sensor of another embodiment of the present invention;

Fig. 10 is a connection diagram of the magnetic angular sensor of Fig. 9;

Fig. 11 is a circuit construction diagram for an electric driven power steering construction according to the present invention;

Fig. 12 is a flow-chart for calculating a torque according to the present invention;

Fig. 13 is an illustration for explaining an operation for an electric driven power steering construction according to the present invention;

Fig. 14 is a flow-chart of detection of a speed and a position of the other embodiment for an electric driven power steering construction according to the present invention;

Fig. 15 is a structural view of a torque controlling apparatus using the torque sensor according to the present invention;

Fig. 16 is a schematic structural view another embodiment of an electric driven power steering assisting apparatus for an automobile according to the present invention;

Fig. 17 is diagrams of detection of a fault according to the present invention;

Fig. 18 is a flow-chart of detection of a fault according to the present invention;

Fig. 19 is a flow-chart of one embodiment of a countermeasure to noise according to the present invention;

Fig. 20 is a flow-chart of a normal operation of one embodiment of assist for an electric driven power steering construction of an automobile;

Fig. 21 is a flow-chart of an abnormality processing of one embodiment of assist for an electric driven power steering construction of the automobile;

Fig. 22 is a flow-chart of another embodiment covering a procedure from judgment of a fault to the abnormality processing according to the present invention; and

Fig. 23 is a schematic structural view of still another embodiment of a torque detecting apparatus according to the present invention.

Description of the Invention:

One embodiment of a torque detecting apparatus will be explained according to the present invention.

In Fig. 1, a rotating drive shaft 1 has rotary drums 2A and 2B at both end portion. The rotating drive shaft 1 serves also as a drive shaft. The rotary drums 2A and 2B have magnetic substances 3A and 3B whereon magnetic signals N · S are recorded are fixed separately by a gap L on the rotating drive shaft 1.

Magnetic angular sensors 4A and 4B are constructed of magneto-resistance effect elements (hereinafter called as MR elements). These magnetic angular sensors 4A and 4B face the rotary drums 2A and 2B respectively and are disposed with a small gap therefrom. A description will be made hereupon in respect to the operations of the rotary drums 2A and 2B and the magnetic angular sensors 4A and 4B by using Fig. 2.

Fig. 2 shows the rotary drum 2A and the magnetic angular sensor 4A taken out for explaining the operations. As mentioned above, the magnetic signals of N and S are recorded on the whole circumference of the magnetic substance 3A of the rotary drum 2A, and the magnetic angular sensor 4A constructed of MR elements R_1, R_2, R_3 and R4 is disposed oppositely thereto with the small gap ℓ therefrom.

Fig. 3A and Fig. 3B are enlarged developed views showing the relationship in disposition between the magnetic substance 3A on the rotary drum 2A and the magnetic angular sensor 4A, which are shown in Fig. 2. In Fig. 3B, the MR elements R_1, R_3, R_2 and R_4 are disposed separately by $\lambda/4$ in relation to a magnetic recording wavelength (a gap between an N-pole and an S-pole) λ.

Fig. 4 shows the operating waveforms of the MR elements. In Fig. 4, the magnetic substance 3A of the rotary drum 2A moves as indicated by an arrow mark shown in the figure, with the rotation of the rotary drum 2A. On the other hand, the MR elements R_1 and R_2 have a characteristic that the resistance value thereof lowers when either one signal of magnetic flux variation of the N-pole and the S-pole of the magnetic signals is applied thereto, as is known well.

When the magnetic substance 3A moves as indicated by the arrow mark, therefore, the changes of resistances of the MR elements R_1 and R_2 are obtained in accordance with the recording wavelength λ, and the change of resistance of each MR element has a waveform shifted in phase by $\lambda/2$ from that of the other.

The MR elements R_1 and R_2 are connected in series as shown in Fig. 5, and an output terminal E_{A1} is taken out from the middle point of the MR elements and connected to three-terminals including the output terminal E_{A1}. When a voltage V is applied to the opposite both ends, a voltage obtained then from the output terminal E_{A1} has a waveform as shown in Fig. 6A, and thus an output E_{A1} corresponding to the magnetic signal recorded on the magnetic substance 3A can be obtained. The MR elements R_3 and R_4 are shifted by $\lambda/4$ from the MR elements R_1 and R_2, and therefore an output E_{B1} being different in phase by 90 degrees from the output E_{A1} is obtained likewise from the MR elements R_3 and R_4.

Besides, waveforms or outputs E_{A2} and E_{B2} shown in Fig. 6B are obtained likewise from the rotary drum 2B and the magnetic angular sensor 4B of Fig. 1 by the same operation.

When a motor is fitted on the drive side of the rotating drive shaft 1 and a load on the load side thereof, for instance, in the torque detecting apparatus of Fig. 1, the rotating drive shaft 1 is twisted by an angle θ in proportion to a load torque given thereto. This relationship is expressed by the following equation.

$$\theta = \frac{32}{\pi \cdot G} \times \frac{L}{D^4} \times T \quad \ldots (1)$$

Herein mark θ denotes a torsion angle (rad), G a shear coefficient (kg/cm^2) of the rotating drive shaft 1, L a distance (cm) between the rotary drums 2A and 2B, and D the diameter (cm) of the rotating drive shaft 1. The shear coefficient G is determined by the material of the rotating drive shaft 1, and so a torque T in relation to the torsion angle θ is found when the distance L between the rotating drums 2A and 2B and the diameter D of the rotary drive shaft 1 are set. Accordingly, the measurement of the torque is enabled by detecting the torsion angle θ of the rotating drive shaft 1.

One example of a method for measuring the torsion angle θ of the rotating drive shaft 1 is shown in Fig. 7A and Fig. 7B. In Fig. 7A, the torsion θ of the rotating drive shaft 1 is found by measuring a phase difference ($\theta_2 \cdot \theta_1$) at the zero cross of the magnetic angular sensor 4A and the output E_{A2} obtained from the rotary drum 2B and the magnetic angular sensor 4B.

As shown in Fig. 7A, in other words, the amount of the torsion of the rotating drive shaft 1 is small when the load torque is small, and therefore a phase difference θ_s at the zero cross of the outputs E_{A1} and E_{A2} turns to be small as well.

In the case when the load torque is large as shown in Fig. 7B, to the contrary, the amount of the torsion of the rotating drive shaft 1 is also increased, and therefore a phase difference θ_m at the zero cross turns to be large. Accordingly, the amplitude of the torque can be detected by measuring this phase difference θ_s or θ_m.

While the phase difference at the zero cross of the signals of the outputs E_{A1} and E_{A2} of the magnetic angular sensors 4A and 4B is determined in the example of Fig. 7, the torque can be detected also in a place other than the zero cross. When the outputs E_{A1} and E_{B1}, and the outputs E_{A2} and E_{B2} are sine waves, the angles of the magnetic drums can be measured from the amplitudes of the sine waves respectively, and therefore the torque can be measured with high resolution by finding the difference between the angles of the rotary drums 4A and 4B.

Fig. 8A and Fig. 8B are illustrations of the principle on the basis of which sine waves are obtained by the magnetic angular sensor 4A of MR elements. Magneto-resistance effect elements (MR elements) R_{11} and R_{15}, and MR elements R_{12} and R_{16} of the magnetic sensor 4 are disposed separately by $\lambda/2$ in relation to a recording wave λ, while the MR elements R_{11} and R_{12}, and the MR elements R_{15} and R_{16}, are disposed separately by $\lambda/6$ from each other, respectively.

Since the MR elements R_{11}, R_{12}, R_{15} and R_{16} are connected in such a disposition as shown in Fig. 8B, an output e_a obtained from the MR elements R_{11} and R_{15} turns to be one as indicated by a solid line e_a of Fig. 8A when the rotary drum 2A rotates.

This waveform distortion occurs because the change of resistance of the MR element is saturated in relation to a magnetic field. Therefore the main component of this distorted wave is a tertiary harmonic, and the wave can be separated into a fundamental wave e_{a1} and the tertiary harmonic e_{a3} as indicated by broken lines in Fig. 8A.

An output e_b obtained from the MR elements R_{16} and R_{12} is turned also into a fundamental wave e_{b1} and a tertiary harmonic e_{b3}. When a bridge output ($e_a + e_b$) i.e., the output E_{A1}, shown in a connection diagram is considered, the tertiary harmonics e_{a3} and e_{b3} are reverse in phase to each other and canceled by each other consequently, and thus only the fundamental wave is obtained.

Fig. 9 is a developed view of a magnetic substance of a rotary drum and a magnetic angular sensor of one embodiment wherein the magnetic angular sensor outputting a sine wave is employed for the torque sensor.

A base 41 is formed of a glass material or the like and bearing MR elements. A rotary drum 21 on the drive side is provided with a magnetic track 311 of a magnetic substance, whereon magnetic signals of N-S are recorded successively at a recording pitch λ. There are two magnetic tracks 321 and 322 on a rotary drum 22 on the load side, and magnetic signals of the recording pitch λ are recorded on magnetic track 321 successively in the same way as on the magnetic track 311 of the rotary drum 21.

On the magnetic track 322, only one magnetic signal of the recording pitch λ is recorded. On a magnetic angular sensor 4 facing the rotary drums 21 and 22, MR elements R_{11}-R_{18} and R_{21}-R_{28} are disposed as shown in the figure. Namely, for the rotary drum 21, MR elements R_{11}-R_{18} are disposed for the rotary track 321, and MR elements R_{21}-R_{28} are disposed for the magnetic track 321 of the rotary drum 22. Moreover, MR elements R_{31} and R_{32} are disposed for the magnetic track 322.

Besides, the MR elements R_{11} and R_{12}, R_{13} and R_{14}, R_{15} and R_{16}, R_{17} and R_{18}, R_{21} and R_{22}, R_{23} and R_{24}, R_{25} and R_{26}, and R_{27} and R_{28}, are disposed separately by $\lambda/6$ from each other, respectively, while the MR elements R_{11}, R_{13}, R_{15}, R_{17}, and R_{21}, R_{23}, R_{25}, R_{27}, and further R_{31}, R_{32}, are disposed separately by $\lambda/4$ from each other, respectively.

The magnetic angular sensor has at least four sets of a first MR element array having MR elements and a second MR element array having MR elements disposed separately by an electrical angle of n ± $\lambda/6$ (n:an

integer) from each other respectively, and a third MR element array having MR elements delivering a reference signal. The respective two sets of the first MR element array and the second MR element array are disposed separately by an electric angle of n ± λ/6 from each other. The two sets of the first MR element array and the second MR element array are disposed separately by each other by n ± λ/6 from each other being spaced by an electrical angle of n ± λ/6 from the other two sets of MR element arrays.

These MR elements are connected in such a manner as shown in Fig. 10, so as to obtain outputs e_0-e_8 therefrom. The outputs e_1-e_2, e_3-e_4, e_5-e_6 and e_7-e_8 of bridges formed by the MR elements R_{11}, R_{12}, R_{15} and R_{16}, R_{13}, R_{14}, R_{17} and R_{18}, R_{21}, R_{22}, R_{25} and R_{26}, and R_{23}, R_{24}, R_{27} and R_{16}, have the same constructions as that in Fig. 8, and sine-wave outputs are obtained therefrom. The output formed by the MR elements R_{31} and R_{32} is provided for obtaining an output of one pulse in one rotation, which is used as a reference position signal.

These outputs e_0-e_8 are amplified by processing circuits shown in Fig. 11, subjected to analog-digital conversion and taken in a microcomputer (MC) so as to perform the computation of a torque.

Fig. 11 shows a construction wherein differential amplification is conducted by fixed resistors R_{01}-R_{04} and an amplifier AMP_1, and an output thereof is inputted to an analog-digital converter ADC_1. Four sets of the same constructions are employed and four kinds of voltages e_1-e_2, e_3-e_4, e_5-e_6 and e_7-e_8 being equivalent to the output voltages E_{A1}, E_{B1}, E_{A2} and E_{B2} of Fig. 6 are inputted to the respective inputs thereof, while outputs A_1, B_1, A_2 and B_2 are delivered therefrom. Four sets of signals A_1, B_1, A_2 and B_2 converted by ADC_1-ADC_4 are inputted to the microcomputer (MC) respectively.

The reference signal e_0 of one rotation is passed through a comparator (CM_1) and an output pulse thereof is inputted to the microcomputer (MC). A position information, a speed information, a torque output, etc., which are computed on the basis of the reference position signal in the microcomputer (MC), are outputted respectively from output terminals 12, 13 and 14 to send the signals to a system.

Moreover, an abnormality signal is outputted from an output terminal 15 in the case of the torque sensor being faulty, on which a description will be made later. In the microcomputer (MC), an arithmetic operation is executed in conformity with a flow-chart to be shown in Fig. 12, and an output being proportional to a torque is presented to the output terminal 14.

According to the flow-chart of Fig. 12, first the outputs of the magnetic angular sensors 4A, 4B are amplified and then subjected to A/D conversion, and digital values A_1, B_1, A_2, B_2 thus obtained are read in. Next, such a execution as expressed by the following equation is executed by using A_1 and B_1, so as to find an angle θ_1 of the rotary drum 2A.

$\theta_1 = \tan^{-1}\left(\frac{A_1}{B_1}\right)$ (2)

The plus and minus of A_1 and B_1 are discriminated herein, the mode thereof is determined, and the value of θ_1 is decided.

The angle θ_2 of the rotary drum 2B is calculated likewise on the basis of the inputs A_2 and B_2 by the following equation.

$\theta_2 = \tan^{-1}\left(\frac{A_2}{B_2}\right)$ (3)

Next, an angular difference between the rotary drums 2A and 2B, i.e. a torsional angle θ_0, is calculated from the difference between the angles θ_1 and θ_2, and a torque T is calculated by the following equation obtained by transformation of the equation (1).

$$T = \frac{\pi \cdot G \cdot D^4}{32 \cdot L} \times \Theta_0 \quad \ldots \quad (4)$$

Then, the torque T is outputted and a return is made to the initial state. Herein the value θ_1 of the equation (2) can be calculated by using only A_1 or B_1, as expressed by an equation (5). The outputs A_1 and B_2 are varied simultaneously,

$\theta_1 = \sin^{-1}(A_1) = \cos^{-1}(B_1)$ (5)

however, when the outputs of the magnetic angular sensors 4A and 4B are varied due to a change in a small gap (spacing) between the rotary drum 2A or 2B and the magnetic angular sensor 4A or 4B, or the like, and therefore the accuracy can be made higher by such a division of A_1 by B_1 as expressed in the equation (2).

Fig. 13 shows an operation according to the flow-chart of Fig. 12. The signals A_1 and B_1; which are obtained from the MR elements R_{11}-R_{18} constituting the first magnetic angular sensor and are inputted to

the microcomputer (MC), are a sine wave and a cosine wave as shown in Fig. 13.

When the plus and minus of signal A_1 and signal B_1 are determined, first, they are divided as indicated by signal A_{1F} and signal B_{1F}. If signal A_{1F} and signal B_{1F} are regarded as signals of 2 bits, they can be divided into four modes shown in Fig. 13.

Besides, the relationship between a value D obtained by dividing the sine wave A_1 by the cosine wave B_1 and the angle θ_1 is as shown in Fig. 13, and the value thereof turns to be ∞ at each angle of $\pm$ 90 degrees and each angle 180 degrees.

Regarding the signals A_2 and B_2 obtained from the MR elements R_{21}-R_{28} constituting the second magnetic sensor, such a relationship between the angle θ_2 and the value D as shown in Fig. 13 can be obtained also just in the same way. Although the value D of A_1/B_1 is the same at two points between 0° and 360°, the angle thereof can be discriminated because of a difference in a mode.

Now, when the angles θ_1 and θ_2 are determined from the outputs of the first and second magnetic sensors at a point (a), θ_1 = 0 and θ_2 = -30 degrees, and accordingly the angular difference between them is (θ_1 - θ_2) = 30 degrees. A torque corresponding thereto can be calculated from the equation (4). When the angles are measured likewise at a point (b) after a certain time passes from the point (a), θ_1 = 60 degrees and θ_2 = 30 degrees, thus the angular difference (θ_1 - θ_2) turning to be 30 degrees. Accordingly, the same torque can be detected at any points on condition that the torque is fixed.

Fig. 14 is a flow-chart for detecting a rotational position and a rotational speed. First the digital inputs A_1 and B_1 of sine waves are taken in, a time $\underline{t}$ of a timer for measuring a speed is read and stored temporarily, and then the timer is re-started. Next, the minute angle θ_1 within one cycle is obtained by the calculation according to the equation (2) in the same way as in the detection of torque.

Then, a minute angle θ_{n-1} obtained previously is read out of a memory, a difference between this angle and the present angle θ_n is calculated to find a change (θ_{n-1} - θ_n) in the angle, value thus found is divided by the time difference $\underline{t}$ between the previous and present angles stored temporarily before, so as to calculate a speed $\underline{v}$, and this is outputted to an output terminal 13.

As for the calculation of a position, the cumulation $\theta_{\Sigma n-1}$ of angles obtained till the preceding time is added to the difference between the present minute angle θ_n and the previous minute angle θ_{n-1}, so as to calculate the current angle $\theta_{\Sigma n}$. Next, the reference position signal is taken in, and when there comes any signal, the current angle θ_n is altered to $\theta_{\Sigma n}$ so as to be matched with a reference value.

Then, the value $\theta_{\Sigma n}$ is outputted to an output terminal 12. Subsequently the present minute position θ_n is put in the memory of θ_{n-1}, while the current angle θ_n is put in the previous angle θ_{n-1}, and a return is made to the start. The foregoing description relates to an example wherein the minute angle θ_n and the previous minute angle θ_{n-1} are found within one cycle, and when the angle is varied beyond one cycle, calculation is conducted by using the cumulation of angles.

Fig. 15 shows a torque controlling apparatus wherein the present torque sensor is employed. A comparison is made between a torque instruction value (CM) and an output of a torque sensor (TS), and an electric current applied to a motor (M) and the direction of rotation thereof are controlled by a control circuit (CC) in accordance with a value obtained from the comparison. This is one example wherein an output of the motor (M) is detected by the torque sensor (TS) and checked and compared with the torque instruction value (CM).

Fig. 16 shows a driving force assisting apparatus using the torque sensor (TS), which is an electric drive power assist steering construction an automobile, in the concrete.

The electric driven power assist steering construction has a construction wherein the torque sensor (TS) of Fig. 1 is fitted to a steering wheel shaft (HS), which is the shaft of a steering wheel (SW), the steering wheel (SW) is provided as the drive side while the torque of the motor (M) is transmitted onto the load side, and a wheel (W) is steered through the intermediary of a pinion gear (PI) and a rack gear (LA) provided in the fore end of the steering wheel shaft (HS).

When a driver operates the steering wheel (SW) and thereby a torque is given to the torque sensor (TS), this torque is detected according to an instruction, and a current or a direction of rotation matched with the torque is outputted by a control circuit (CC) so as to drive the motor (M). The torque of the motor (M) is transmitted for steering through the pinion gear (PI) and the rack gear (LA), so as to compensate the power of the driver.

As is seen from these examples of employment, any fault of the torque sensor (TS) causes a false operation of the driving force assisting apparatus, thus bringing forth a great danger. Fig. 17 shows an example of fault judgment for judging the fault of the torque sensor (TS) to take a step for safety quickly. This figure shows the waveforms of the signals A_1 and B_1 of Fig. 11.

The signals A_1 and B_1 appear normally between the times t_1 and t_2 and the signal B_1 turns faulty due to a fault at the time t_2 in this example. Values of the output are varied from (a) to (n) according to the

cause of abnormality, and the output ceases to vary when the abnormality occurs. In contrast, the signal A_1 continues to give a normal output.

Accordingly, the occurrence of the fault can be detected by checking that the signal B_1 is not varied while the signal is varied. The same can be detected also by checking a state of variation of the signal A_1 while the signal B_1 is varied.

Fig. 18 is a flow-chart for detecting abnormality. First the signals A_1 and B_1 are taken in, and a mode is determined from each signal. Next, values $A_{1(n-1)}$ and $B_{1(n-1)}$ of the previous signals stored in a memory are compared sequentially with the present values. Judgment of being normal is made when both signals are varied or when neither of them is varied, and the calculation of a normal torque is conducted so as to execute normal driving.

When the comparison of the signals A_1 and B_1 with the previous values shows that one of them is varied while the other is not varied, either one of the signals is judged to be abnormal, and a processing to cope with the abnormality is executed. The same operation is conducted also with regard to the signals A_2 and B_2.

Fig. 19 is a flow-chart for preventing the judgment of abnormality due to electric noise. According to this flow-chart, the signal A_1 or B_1 is read twice at a certain short time interval, and the judgment of being abnormal is made when the values thereof are equal substantially, while the judgment of being affected by noise is made when the values are different in a large degree. In the latter case, the judgment of being abnormal is not made and a return is made to the start.

Fig. 20 shows a sequence of normal operations in the case when it is applied to the driving force assisting apparatus shown in Fig. 16, that is, to the assistance of steering of an automobile. In the normal operations, the torque of a motor is decided and the direction of rotation of the motor is determined in accordance with an output of the torque sensor, and subsequently a current made to flow through the motor and the direction of rotation are outputted.

Fig. 21 shows one example of a processing in abnormality in the case when it is used for a steering force assisting control apparatus of the same automobile. First an abnormality signal and an alarm are outputted. Then, driving f the motor is stopped, and simultaneously a clutch fitted onto the load side is released so that the motor may not be a load on steering.

Fig. 22 is a flow-chart of the case when the stop is not made at once even when any abnormality occurs, a torque being detected for some time only by signals of one magnetic sensor, and the processing for the abnormality being executed after some time passes.

First, judgment on a fault is made by a method as shown in Fig. 18, and when the fault is judged to be present, a primary alarm is outputted. Next, the value θ_1 is calculated by using the signal A_1 or B_1 not being faulty. Although modes can not be discriminated due to the fault of one output and consequently two values of θ_1 come out, the value nearer to a value of $\theta_{1(n-1)}$ used in the preceding calculation is selected as θ_1. Then, θ_2 is calculated in the same way, the difference θ between the two angles θ_1 and θ_2 is calculated, and a torque is calculated therefrom.

Subsequently, the number N in the preceding time is made to be (N+1), and it is checked whether N becomes a certain number N_0 or not. The abnormality processing is executed when N is N_0, while a normal operation is conducted when N is less than N_0.

According to this method, the motor is not stopped immediately even when any fault occurs, and it is stopped gradually with a time for preparation secured. Therefore, it may be said that this method is a safe and practical method.

Fig. 23 shows an example of employment of magnetic discs. In this example, the magnetic disks are fixed on the right and left of a shaft, and the positions of the disks are detected by two magnetic sensors facing them respectively.

Claims

1. A torque detecting apparatus comprising a first rotary body (3A; 21) being fitted on a drive side on a rotating drive shaft, a second rotary body (3B; 22) being fitted on a load side on said rotating drive shaft, a first position detecting means (4A; R_{11}-R_{18}) being disposed oppositely and facing said first rotary body, a second position detecting means (4B, R_{21}-R_{28}, R_{31}, R_{32}) being disposed oppositely and facing said second rotary body, said first position detecting means generates a first output (E_{A1}; e_a, e_1, e_3) and a second output (E_{B1}; e_b, e_2, e_4) corresponding to positions of rotation of said first rotary body (3A; 21), said second position detecting means generates a third output (E_{A2}; e_5, e_6) and a fourth output (E_{B2}; e_7, e_8) corresponding to positions of rotation of said second rotary body (3B; 22), and a torque computing means (MC) deriving a

first rotational angle from said first output of said first rotary body and said second output of said first rotary body and deriving a second rotational angle from said third output of said second rotary body and said fourth output of said second rotary body and further computing a torque from a phase difference between said first angle and second rotational angles,

characterized in that

said torque detecting apparatus comprises further a judging means (MC in Fig. 11) judging a fault and for outputting an abnormality signal (15), when one of said first and second output in said first rotary body is detected to be the faulty; said abnormality signal being delivered, if the respective other output of both outputs of said first rotary body is detected to be varied while the one output of both outputs of said first rotary body is detected to be not varied.

2. A torque detecting apparatus according to claim 1, **characterized** in that said means are judging a fault and outputting an abnormality signal, when one of said third and said fourth outputs of said second rotary body is determined to be faulty; said abnormality signal being delivered, if the respective other output of both outputs of said second rotary body is detected to be varied while said one of both outputs of said second rotary body is detected to be not varied.

3. A torque detecting apparatus according to claim 1, **characterized** in that one output of both outputs of said first rotary body is a sine-wave output and the respective other output is a cosine-wave output.

4. A torque detecting apparatus according to claim 2, **characterized** in that one output of both outputs of said second rotary body is a sine-wave output and the respective other output is a cosine-wave output.

5. A torque detecting apparatus according to claim 3, **characterized** in that for deriving the rotational angle of said first rotary body a quotient of said sine-wave output and said cosine-wave output is calculated.

6. A torque detecting apparatus according to claim 4, **characterized** in that, for deriving the rotational angle of said second rotary body a quotient of said sine-wave output and said cosine-wave output is calculated.

7. A torque detecting apparatus according to claim 5, **characterized** in that when one of said sine-wave output and said cosine-wave output of said first rotary body does not change while the respective other output is changed, said unchanged output is determined to be the faulty output and said abnormality signal is generated, while the calculation of the rotational angle is carried out only on the basis of the changing output and a value nearest to a preceding torque is used.

8. A torque detecting apparatus according to claim 6, **characterized** in that, when one of said sine-wave output and said cosine-wave output of said second rotary body does not change while the respective other output is changed, said unchanged output is determined to be the faulty output and said abnormality signal is generated, while the calculation of the rotational angle is carried out only on the basis of the changing output and a value nearest to a preceding torque is used.

9. A torque detecting apparatus according to claim 1, **characterized** in that said first rotary body comprises a magnetic drum or a magnetic disc, and said first position detecting means comprises magnetic angular sensor for magnetically detecting an angular position of said first rotary body.

10.A torque detecting apparatus according to claim 2, **characterized** in that said second rotary body comprises a magnetic drum or a magnetic disc, and said second position detecting means coomprises a magnetic angular sensor for magnetically detecting an angular position of said second rotary body.

11. A torque detecting apparatus according to claim 1, **characterized** in that a step of reading said first and second outputs of said first rotary body is repeated by the judging means after a prescribed short time and if values obtained by the repeated reading step are not substantially equal to the preceding ones, said first and second outputs are determined as a noise, while a judgment of being faulty is not made, and a read step is again repeated from the beginning.

12. A torque detecting aparatus according to claim 2, **characterized** in that a step of reading said third and fourth outputs of said second rotary body is repeated by the judging means after a prescribed short time and if values obtained by the repeated reading step are not substantially equal to the preceding ones, said third and fourth outputs are determined as a noise, while a judgment of being faulty is not made, and a read step is again repeated from the beginning.

13. A torque detecting apparatus according to claim 1, **characterized** in that said torque detecting apparatus further comprises an alarm means for giving an alarm when one output of said first output and said second output is determined to be faulty.

14. A torque detecting apparatus according to claim 2, **characterized** in that said torque detecting apparatus further comprises an alarm means for giving an alarm when one output of said third output and said fourth output is determined to be faulty.

15. A torque detecting apparatus according to claim 9, **characterized** in that said magnetic angular sensor comprises on a common base at least four sets of a first and a second magnetro-resistance effect element arrays having magnetro-resistance effect elements (R_{11}-R_{18}) disposed separately by an electrical angle of n ± λ/6 from each other respectively and a third magnetro-resistance effect element array delivering a reference signal, the respective two sets of said first and said second magnetro-resistance effect element arrays being disposed separately by an electrical angle of n ± λ/4 from each other and the two sets of said arrays separated by n ± λ/4 from each other being spaced by an electrical angle of n ± λ /2 from the other two sets thereof, λ being the angular pitch between respective opposite magnetic poles on said magnetic drum or disc (Fig. 9).

16. A torque detecting apparatus according to claim 10, **characterized** in that said magnetic angular sensor comprises on a common base at least four sets of a first and a second magnetro-resistance effect element arrays having magnetro-resistance effect elements (R_{21}-R_{28}) disposed separately by an electrical angle of n ± λ/6 from each other respectively and a third magnetro-resistance effect element array delivering a reference signal are borne by a base, the respective two sets of said first and said second magnetro-resistance effect element arrays being disposed separately by an electrical angle of n ± λ /4 from each other and the two sets of said arrays separated by n ± λ/4 from each other being spaced by an electrical angle of n ± λ/2 from the other two sets thereof, λ being the angular pitch between respective opposite magnetic poles on said magnetic drum or disc (Fig.9).

17. An electric driven power steering apparatus comprising a rotating drive shaft to which a driving force is given manually or mechanically, **characterized** by the use of the apparatus according to one of the preceding claims, and
further comprising control means for controlling an assist torque means to generate an assist torque to be given onto the load side of said rotating drive shaft on a basis of an output of said torque computing means, wherein said assist torque means is rendered ineffective in accordance with the ouput of an abnormality signal.

18. The electric driven power steering apparatus according to claim 17, **characterized** in that said rotating drive shaft is a steering wheel shaft of an automobile, and the drive side is a steering wheel side while the load side is a tire side, said assist torque means is an electric motor and is constructed to assist a steering force.

19. The electric driven power steering apparatus according to claim 18, **characterized** in that said motor is cut off from said rotating drive shaft when said torque detecting apparatus is determined to be abnormal.

FIG. 1

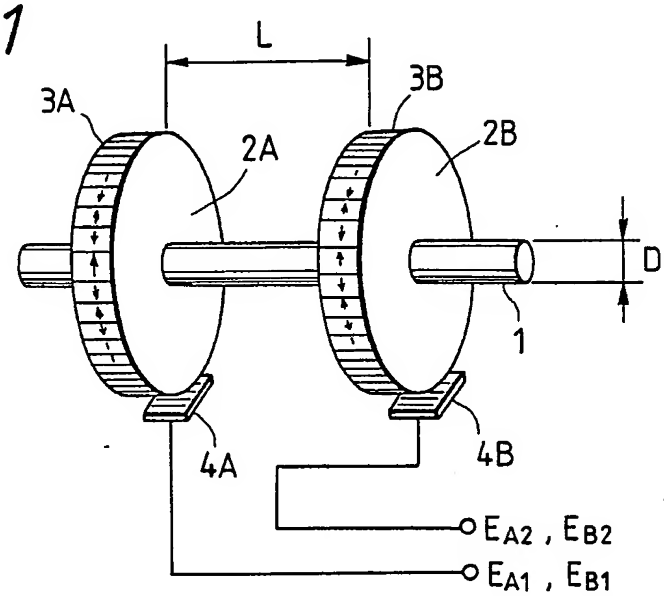


FIG. 2

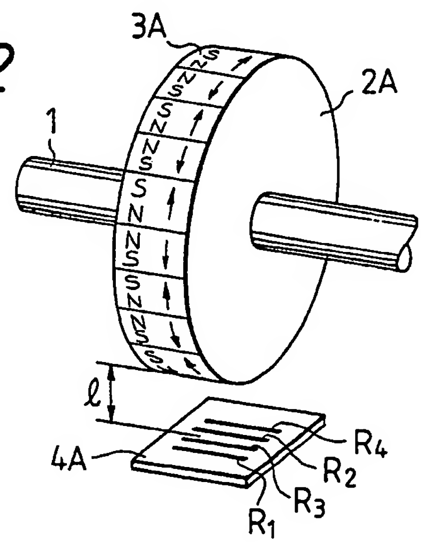


FIG. 3A

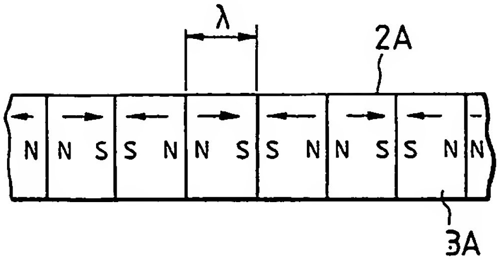


FIG. 3B

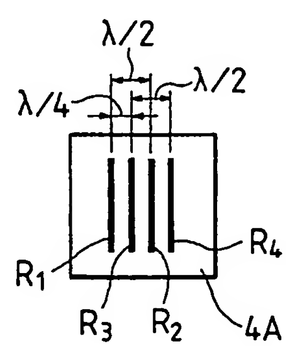


FIG. 4

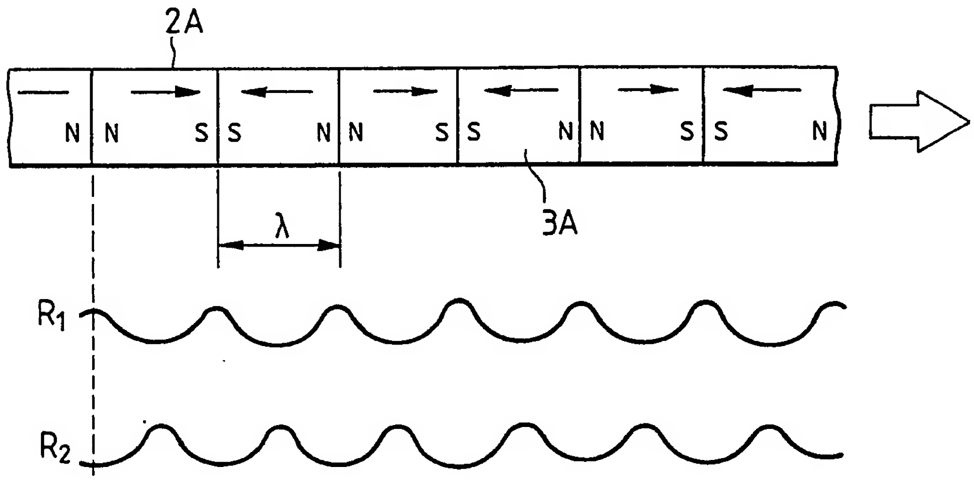


FIG. 5

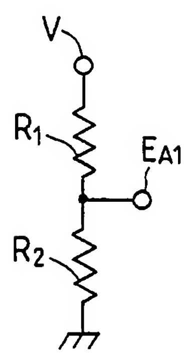


FIG. 6A

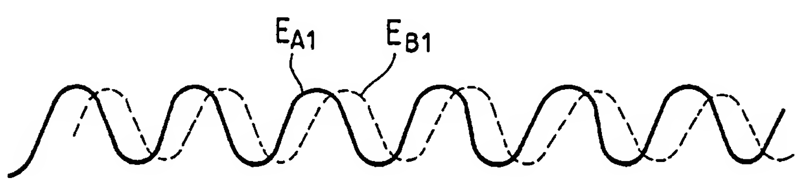


FIG. 6B

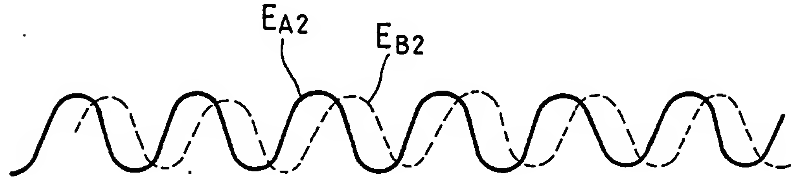


FIG. 7A

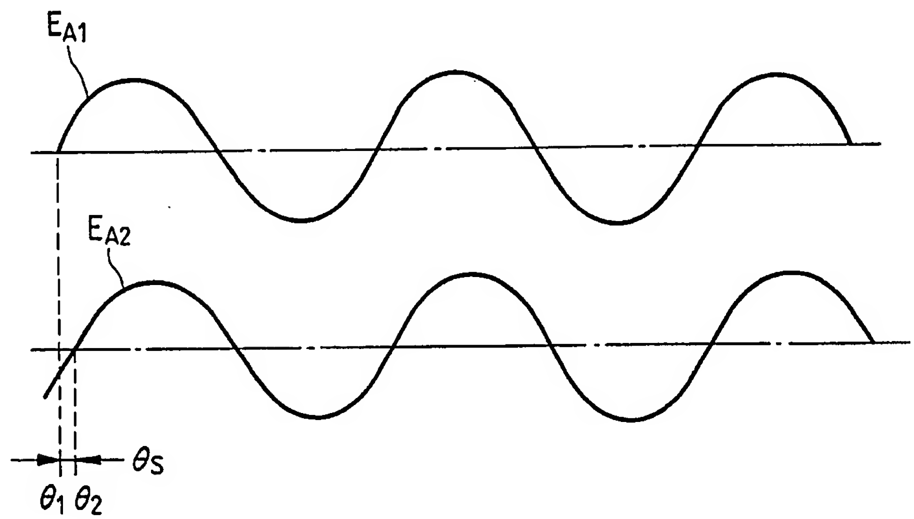


FIG. 7B

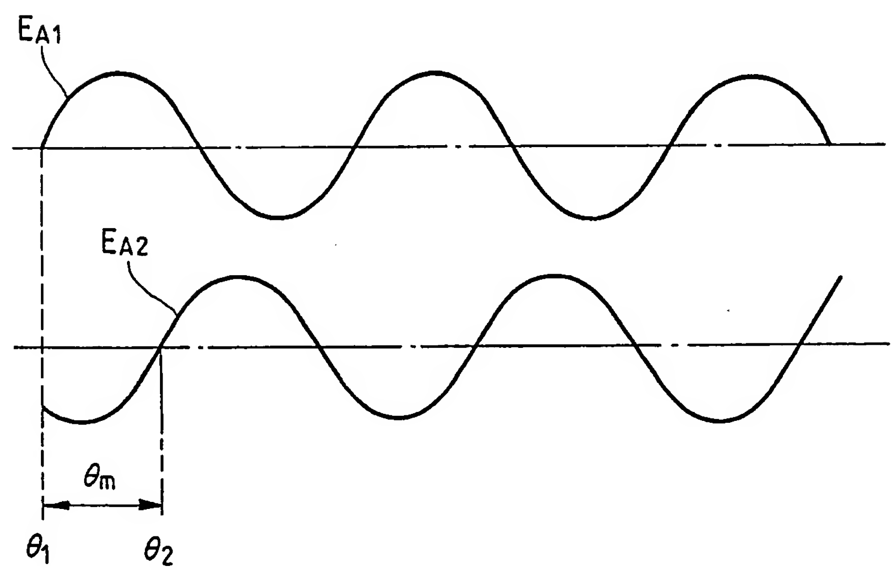


FIG. 8A

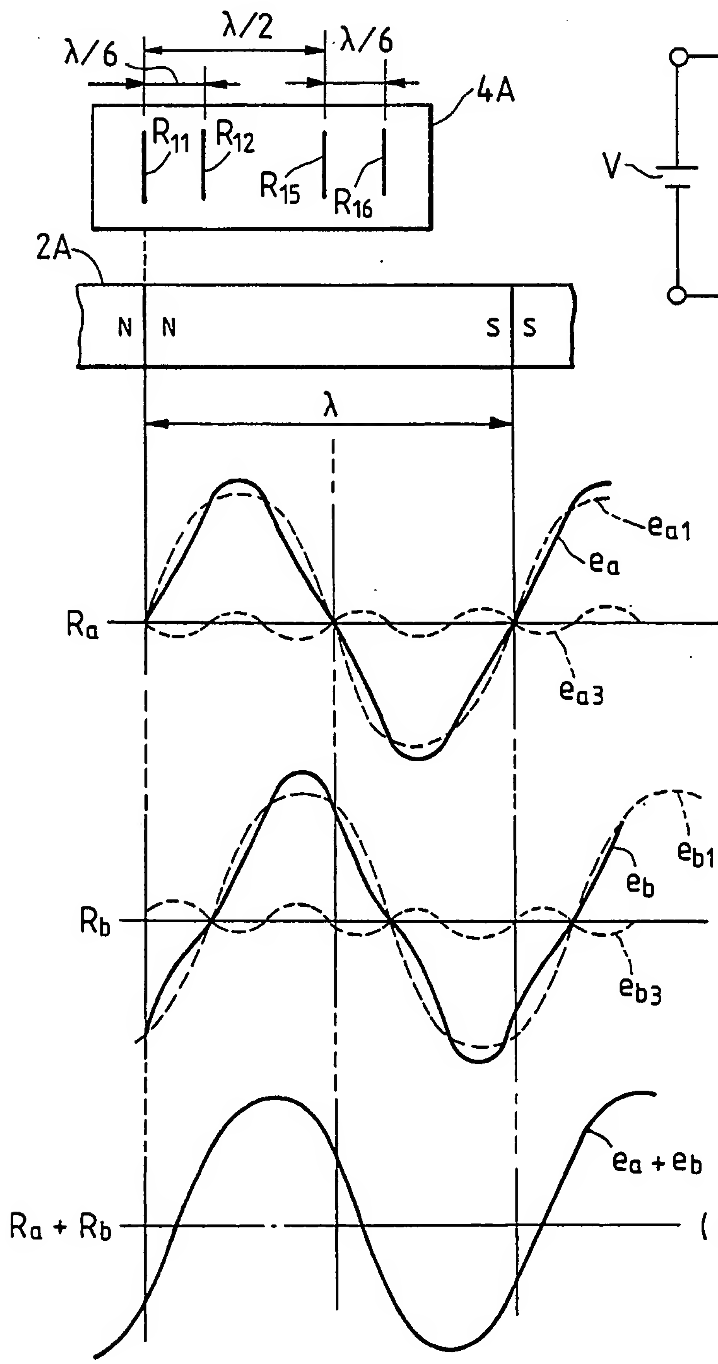

λ/6
λ/2
λ/6
4A
R11
R12
R15
R16
2A
N
N
S
S
λ
ea1
ea
Ra
ea3
eb1
eb
Rb
eb3
ea + eb
Ra + Rb
(EA1)

FIG. 8B

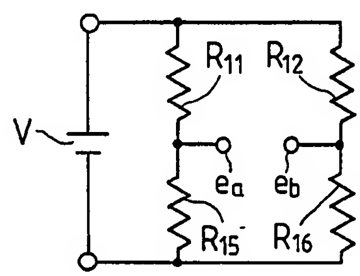
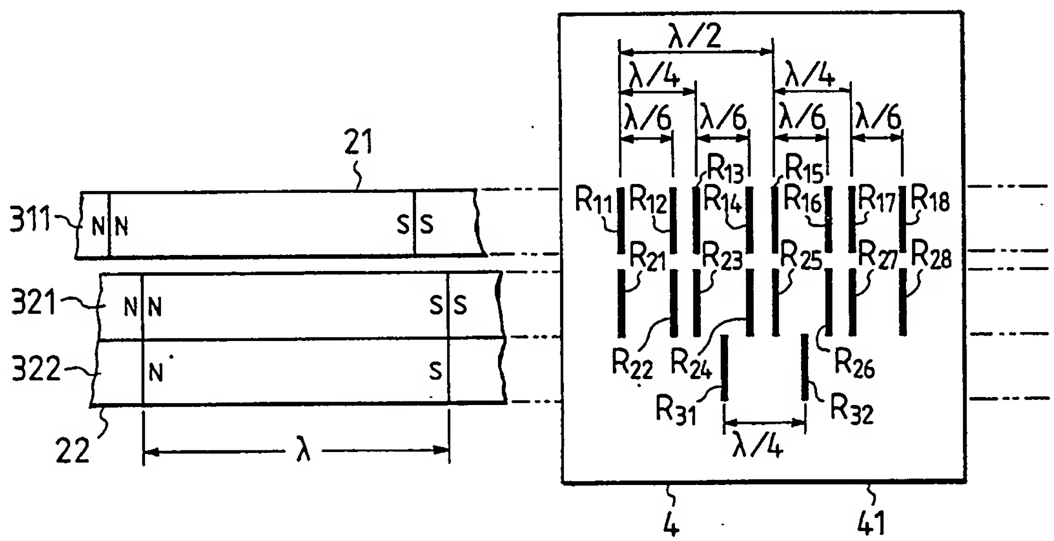
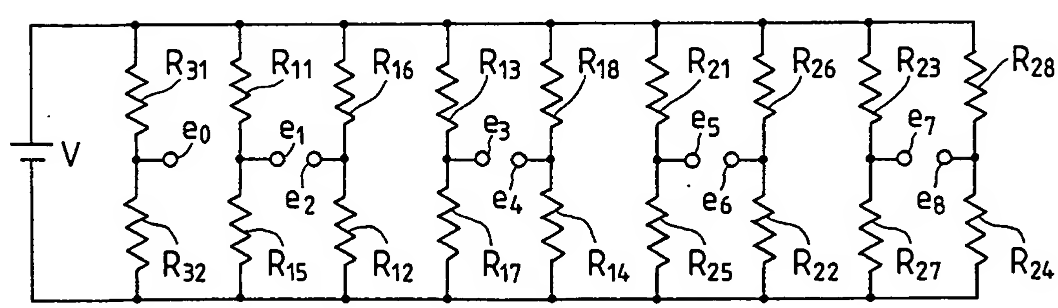

R11
R12
V
ea
eb
R15
R16

FIG. 9



λ/2
λ/4
λ/4
λ/6
λ/6
λ/6
λ/6
21
311
321
322
22
N
S
λ
R11
R12
R13
R14
R15
R16
R17
R18
R21
R22
R23
R24
R25
R26
R27
R28
R31
R32
λ/4
4
41

FIG. 10



V
R31
R32
R11
R15
R16
R12
R13
R17
R18
R14
R21
R25
R26
R22
R23
R27
R28
R24
e0
e1
e2
e3
e4
e5
e6
e7
e8

FIG. 11

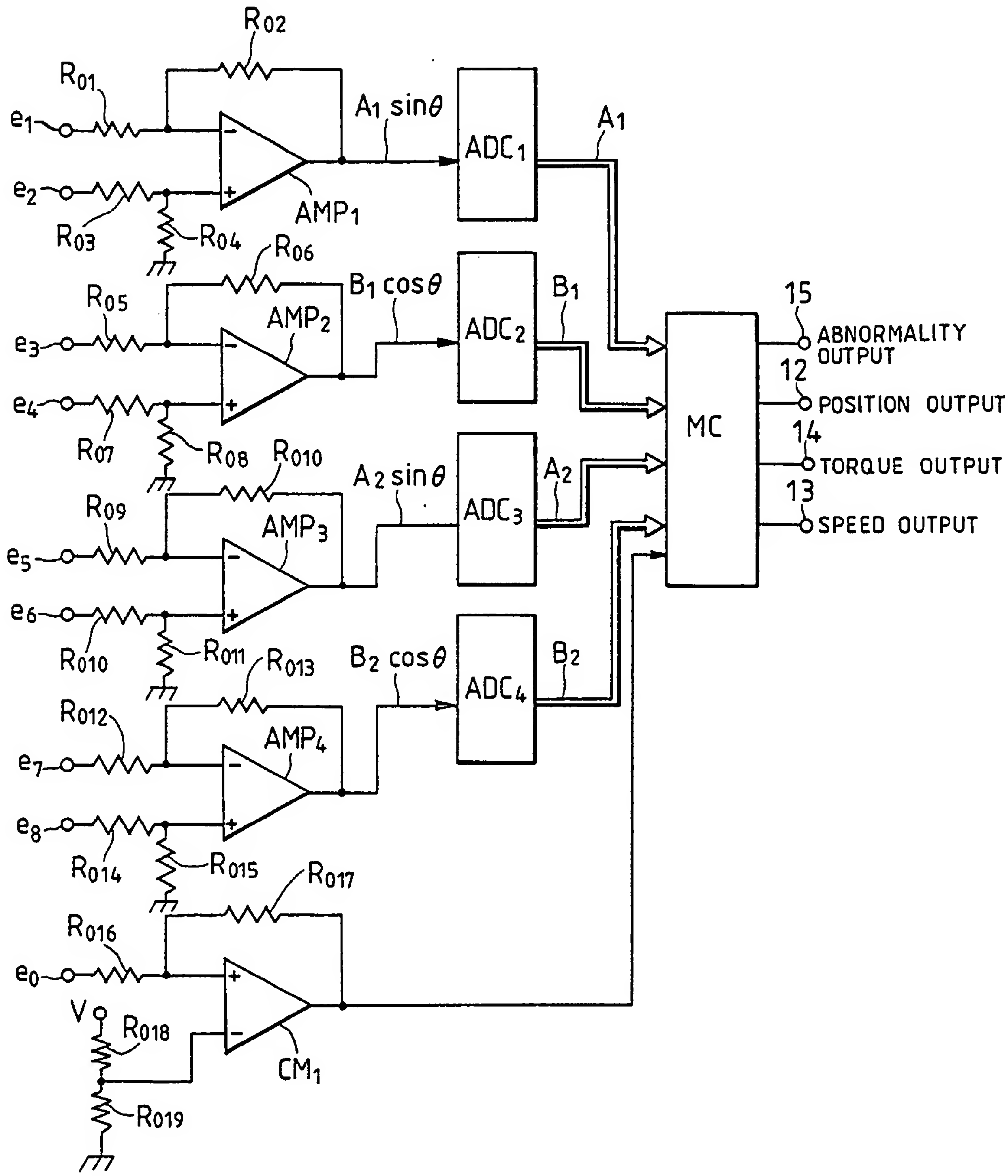

R02
R01
e1
AMP1
e2
R03
R04
A1 sinθ
ADC1
A1
R06
R05
B1 cosθ
AMP2
ADC2
B1
e3
e4
R07
R08
R010
R09
A2 sinθ
AMP3
ADC3
A2
e5
e6
R010
R011
R013
R012
B2 cosθ
AMP4
ADC4
B2
e7
e8
R014
R015
R017
R016
e0
V
R018
CM1
R019
MC
15
ABNORMALITY OUTPUT
12
POSITION OUTPUT
14
TORQUE OUTPUT
13
SPEED OUTPUT

FIG. 12

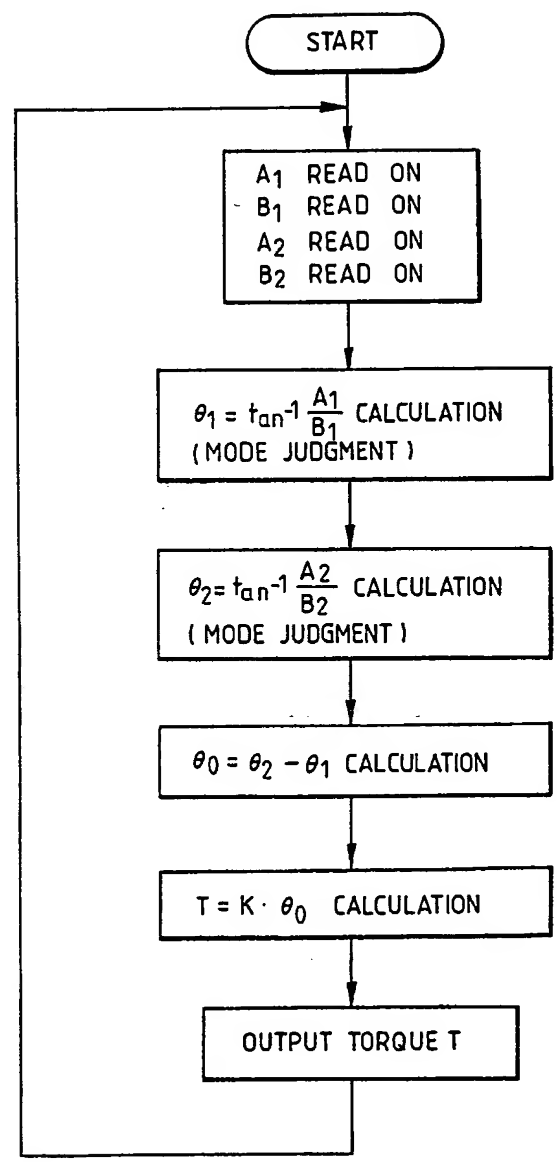

START
A_1 READ ON
B_1 READ ON
A_2 READ ON
B_2 READ ON
$\theta_1 = \tan^{-1} \frac{A_1}{B_1}$ CALCULATION
(MODE JUDGMENT)
$\theta_2 = \tan^{-1} \frac{A_2}{B_2}$ CALCULATION
(MODE JUDGMENT)
$\theta_0 = \theta_2 - \theta_1$ CALCULATION
$T = K \cdot \theta_0$ CALCULATION
OUTPUT TORQUE T

FIG. 13

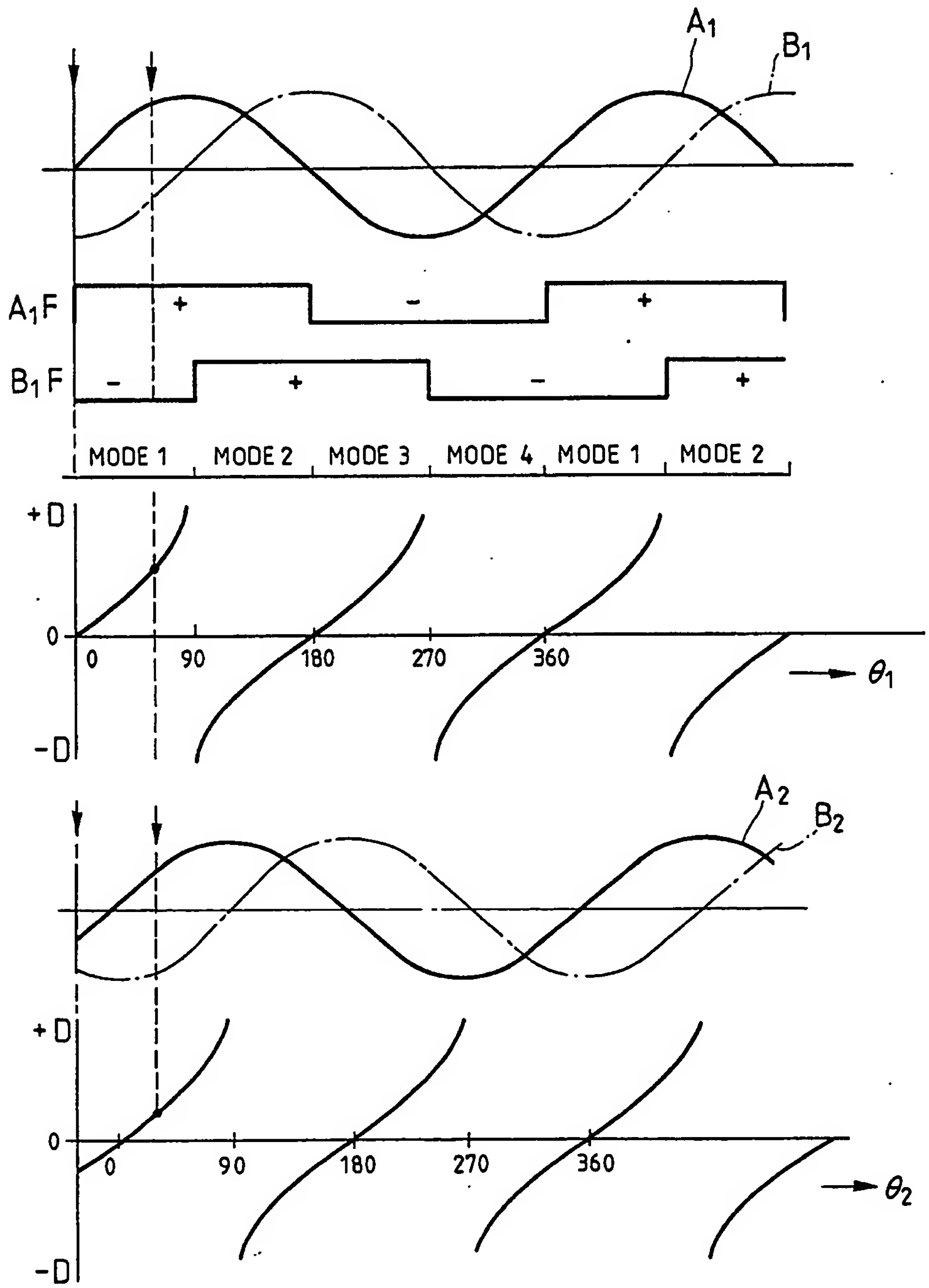

A1
B1
A1F
+
-
+
B1F
-
+
-
+
MODE 1
MODE 2
MODE 3
MODE 4
MODE 1
MODE 2
+D
0
-D
0
90
180
270
360
θ1
A2
B2
+D
0
-D
0
90
180
270
360
θ2

FIG. 14

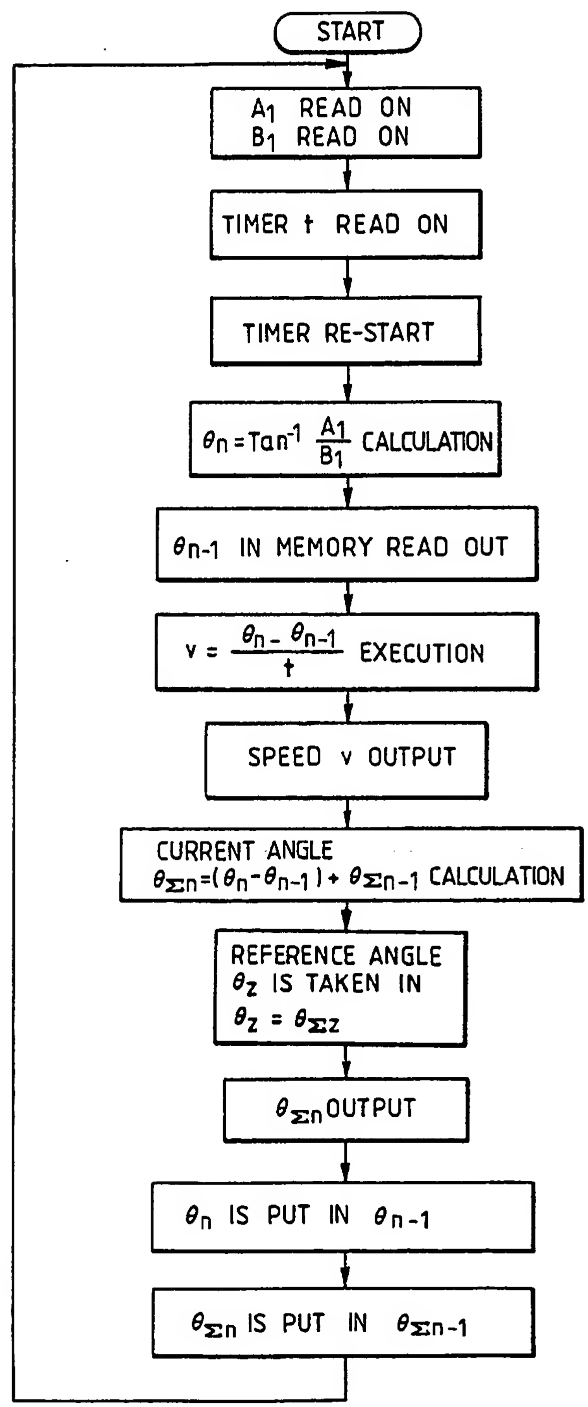

START
A_1 READ ON
B_1 READ ON
TIMER t READ ON
TIMER RE-START
$\theta_n = \mathrm{Tan}^{-1} \frac{A_1}{B_1}$ CALCULATION
θ_{n-1} IN MEMORY READ OUT
$v = \frac{\theta_n - \theta_{n-1}}{t}$ EXECUTION
SPEED v OUTPUT
CURRENT ANGLE
$\theta_{\Sigma n} = (\theta_n - \theta_{n-1}) + \theta_{\Sigma n-1}$ CALCULATION
REFERENCE ANGLE
θ_Z IS TAKEN IN
$\theta_Z = \theta_{\Sigma Z}$
$\theta_{\Sigma n}$ OUTPUT
θ_n IS PUT IN θ_{n-1}
$\theta_{\Sigma n}$ IS PUT IN $\theta_{\Sigma n-1}$

FIG. 15

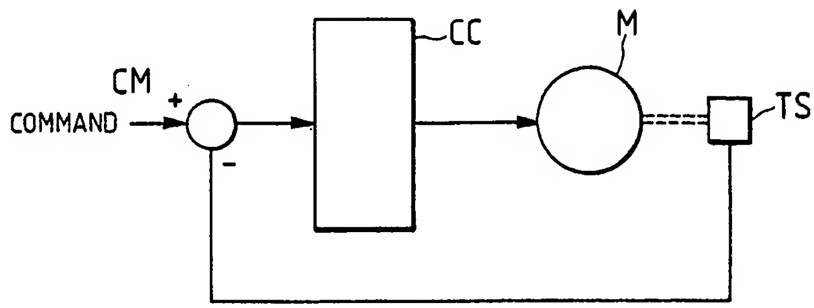


FIG. 16

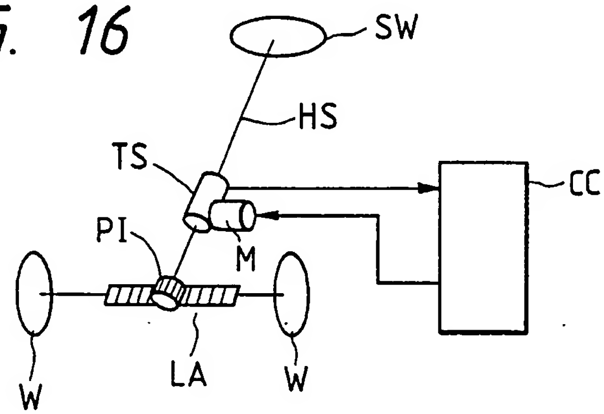


FIG. 17

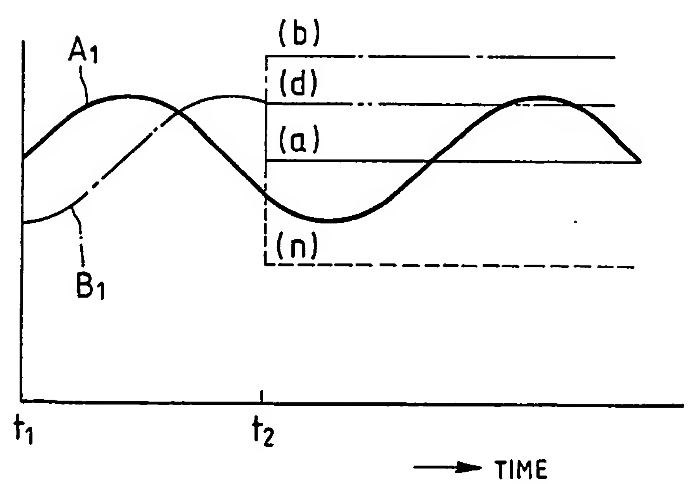


FIG. 18

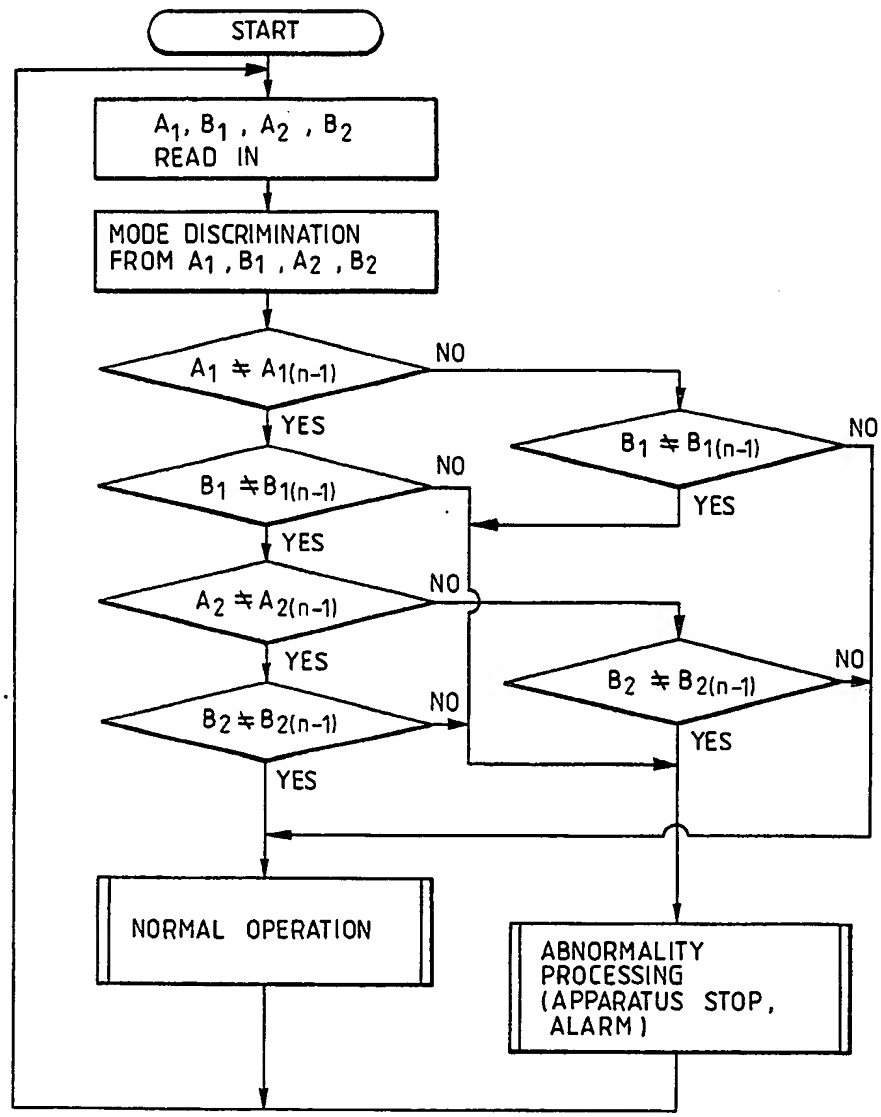

START
A1, B1, A2, B2
READ IN
MODE DISCRIMINATION
FROM A1, B1, A2, B2
A1 ≒ A1(n-1)
NO
YES
B1 ≒ B1(n-1)
NO
YES
B1 ≒ B1(n-1)
NO
YES
A2 ≒ A2(n-1)
NO
YES
B2 ≒ B2(n-1)
NO
YES
B2 ≒ B2(n-1)
NO
YES
NORMAL OPERATION
ABNORMALITY
PROCESSING
(APPARATUS STOP,
ALARM)

FIG. 19

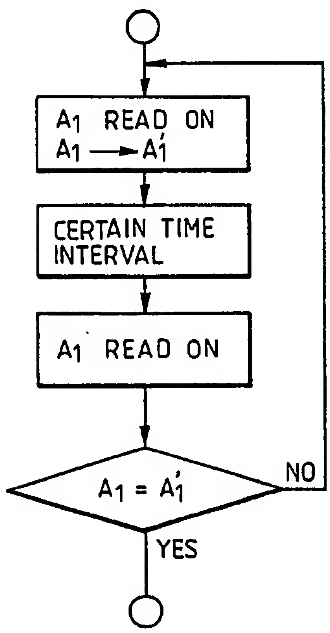


FIG. 20

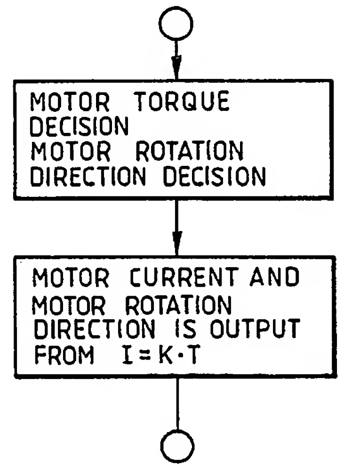


FIG. 21

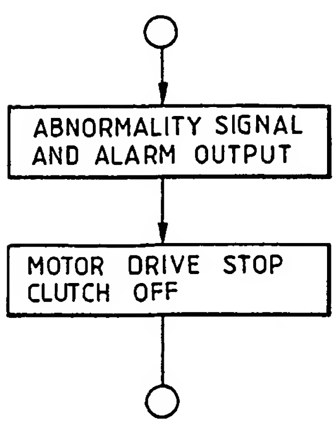


FIG. 23

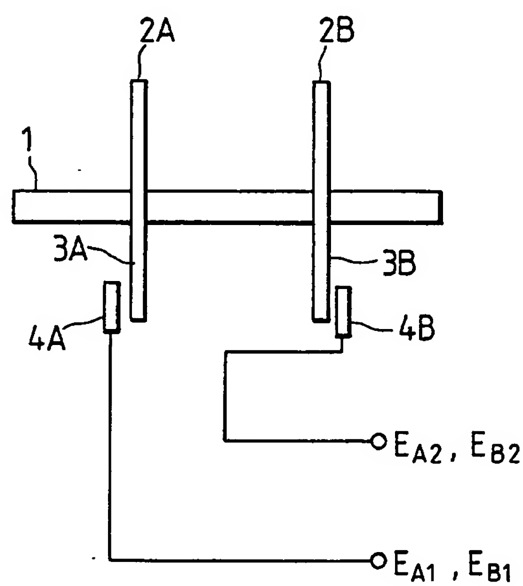
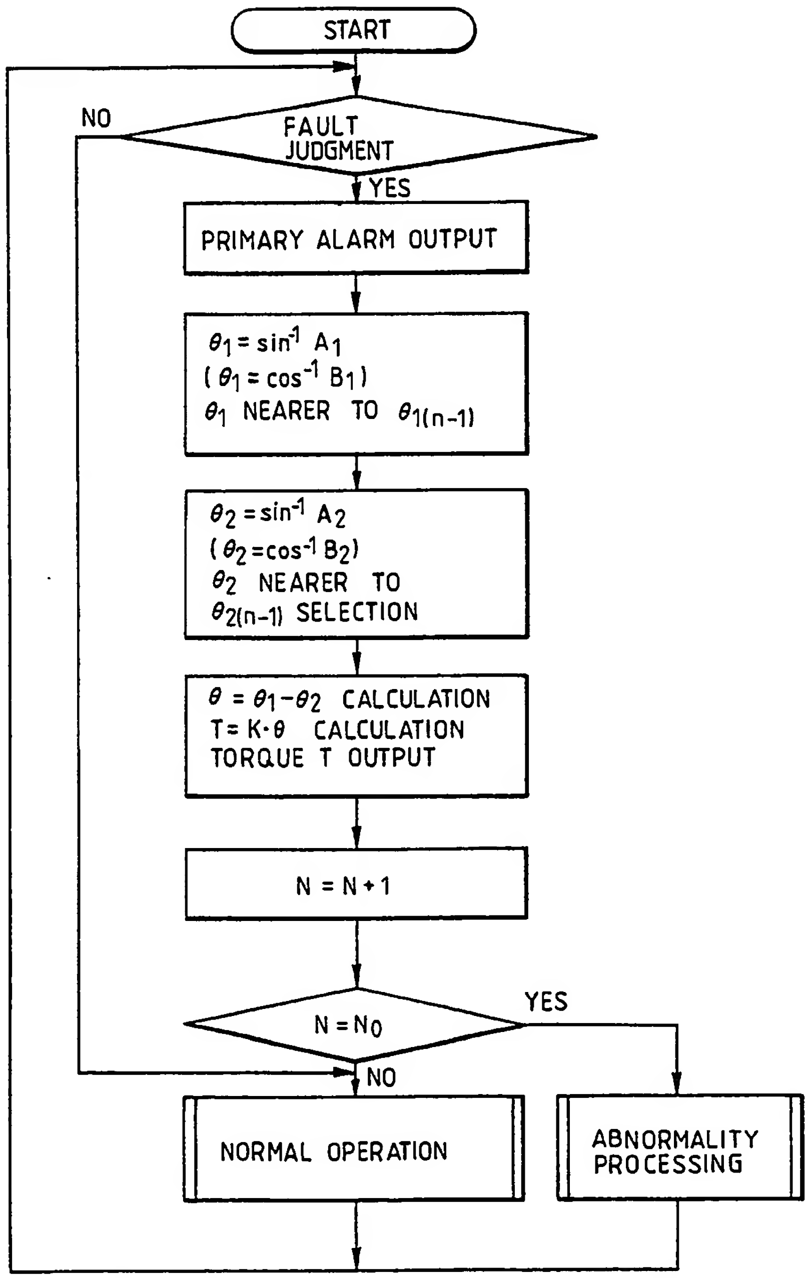


FIG. 22


START
FAULT JUDGMENT
NO
YES
PRIMARY ALARM OUTPUT
θ1 = sin-1 A1
(θ1 = cos-1 B1)
θ1 NEARER TO θ1(n-1)
θ2 = sin-1 A2
(θ2 = cos-1 B2)
θ2 NEARER TO
θ2(n-1) SELECTION
θ = θ1−θ2 CALCULATION
T= K·θ CALCULATION
TORQUE T OUTPUT
N = N + 1
N = N0
YES
NO
NORMAL OPERATION
ABNORMALITY PROCESSING